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Methods And Compositions For Detecting CDN Apoptosis-Modulating Proteins

~~NOVEL APOPTOSIS-MODULATING PROTEINS, DNA ENCODING THE PROTEINS AND METHODS OF USE THEREOF~~

This is a continuation-in-part of United States patent application Serial No. 08/160,067 filed November 30, 1993, abandoned.

Field of the Invention

This invention relates to novel proteins with apoptosis-modulating activity, recombinant DNA encoding the proteins, compositions containing the proteins and methods of use thereof.

Background of the Invention

Apoptosis is a normal physiologic process that leads to individual cell death. This process of programmed cell death is involved in a variety of normal and pathogenic biological events and can be induced by a number of unrelated stimuli. Changes in the biological regulation of apoptosis also occur during aging and are responsible for many of the conditions and diseases related to aging. Recent studies of apoptosis have implied that a common metabolic pathway leading to cell death may be initiated by a wide variety of signals, including hormones, serum growth factor deprivation, chemotherapeutic agents, ionizing radiation and infection by human immunodeficiency virus (HIV). Wyllie (1980) Nature, 284:555-556; Kanter et al. (1984) Biochem. Biophys. Res. Commun. 118:392-399; Duke and Cohen (1986) Lymphokine Res. 5:289-299; Tomei et al. (1988) Biochem. Biophys. Res. Commun. 155:324-331; Kruman et al. (1991)

J. Cell. Physiol. 148:267-273; Ameisen and Capron (1991) Immunology Today 12:102; and Sheppard and Ascher (1992) J. AIDS 5:143. Agents that modulate the biological control of apoptosis thus have therapeutic utility in a wide variety of conditions.

Apoptotic cell death is characterized by cellular shrinkage, chromatin condensation, cytoplasmic blebbing, increased membrane permeability and interchromosomal DNA cleavage. Kerr et al. (1992) FASEB J. 6:2450; and Cohen and Duke (1992) Ann. Rev. Immunol. 10:267. The blebs, small, membrane-encapsulated spheres that pinch off of the surface of apoptotic cells, may continue to produce superoxide radicals which damage surrounding cell tissue and may be involved in inflammatory processes.

Bcl-2 was discovered at the common chromosomal translocation site t(14:18) in follicular lymphomas and results in aberrant over-expression of bcl-2. Tsujimoto et al. (1984) Science 226:1097-1099; and Cleary et al. (1986) Cell 47:19-28. The normal function of bcl-2 is the prevention of apoptosis; unregulated expression of bcl-2 in B cells is thought to lead to increased numbers of proliferating B cells which may be a critical factor in the development of lymphoma. McDonnell and Korsmeyer (1991) Nature 349:254-256; and, for review see, Edgington (1993) Bio/Tech. 11:787-792. Bcl-2 is also capable of blocking of γ irradiation-induced cell death. Sentman et al. (1991) Cell 67:879-888; and Strassen (1991) Cell 67:889-899. It is now known that bcl-2 inhibits most types of apoptotic cell death and is thought to function by regulating an antioxidant pathway at sites of free radical generation. Hockenbery et al. (1993) Cell 75:241-251.

While apoptosis is a normal cellular event, it can also be induced by pathological conditions and a

variety of injuries. Apoptosis is involved in a wide variety of conditions including but not limited to, cardiovascular disease, cancer regression, immunoregulation, viral diseases, anemia, neurological disorders, gastrointestinal disorders, including but not limited to, diarrhea and dysentery, diabetes, hair loss, rejection of organ transplants, prostate hypertrophy, obesity, ocular disorders, stress and aging.

Bcl-2 belongs to a family of proteins some of which have been cloned and sequenced. Williams and Smith (1993) Cell 74:777-779. All references cited herein, both supra and infra, are hereby incorporated by reference herein.

Summary of the Invention

Substantially purified DNA encoding novel bcl-2 homologs, termed cdn-1, new cdn-2 and cdn-3, as well as recombinant cells and transgenic animals expressing the cdn-1 and cdn-2 genes are provided. The substantially purified CDN-1 and CDN-2 proteins and compositions thereof are also provided. Diagnostic and therapeutic methods utilizing the DNA and proteins are also provided. Methods of screening for pharmaceutical agents that stimulate, as well as pharmaceutical agents that inhibit cdn-1 and cdn-2 activity levels are also provided.

Brief description of the Drawings

Figure 1 depicts the PCR primers (SEQ ID NO:1 through SEQ ID NO:5) used to isolate the cdn-1 probes.

Figure 2 depicts the cdn-1 clones obtained by the methods described in Example 1.

Figure 3 depicts the nucleotide sequence (SEQ ID NO:6 and SEQ ID NO:7) of cdn-1 and translated amid acid.

genes. The nucleotide and predicted amino acid residue sequences of cdn-1 are shown in Figure 3; and those of cdn-2 are shown in Figure 5. It has now been found that the proteins encoded by the cdn genes are capable of modulating apoptosis. In a lymphoblastoid cell line, cdn-1 was shown to decrease Fas-mediated apoptosis. In a mouse progenitor B cell line, FL5.12, cdn-2 and a derivative of cdn-1 decrease IL-3-induced apoptosis whereas cdn-1 slightly increased apoptosis. Thus, depending on the cell type, the derivative of cdn and the method of induction of apoptosis, apoptosis can be modulated in a highly specific manner by controlling the concentration of cdns.

As used herein, "cdns" or "cdn" refers to the nucleic acid molecules described herein (cdn-1, cdn-2, cdn-3 and derivatives thereof), "the CDNs" or "CDN" refers to the proteins encoded thereby (CDN-1, CDN-2, CDN-3 and derivatives thereof). The present invention encompasses cdn-1 and cdn-2 nucleotide sequences. The cdn nucleotides include, but are not limited to, the cDNA, genome-derived DNA and synthetic or semi-synthetic DNA or RNA. The nucleotide sequence of the cdn-1 cDNA with the location of restriction endonuclease sites is shown in Figure 2. As described in the examples herein, cdn-1 mRNA has been detected in a variety of human organs and tissues by Northern blot analysis. These organs include liver; heart; skeletal muscle; lung; kidney; and pancreas as shown in Figure 3.

Similarly, cdn-2, cdn cDNA, genomic DNA and synthetic or semi-synthetic DNAs and RNAs are additional embodiments of the present invention. The nucleotide sequence of cdn-2 cDNA, along with the predicted amino acid sequence of cdn-2 protein and the locations of restriction endonuclease recognition sites, is given in Figure 5. The examples presented herein indicate that

Figure 4 depicts the results of a Northern blot analysis of multiple tissues with probes specific for both bcl-2 and cdn-1.

Figure 5 (SEQ ID NO:8 and SEQ ID NO:9) shows the sequence of the cdn-2 cDNA and flanking sequences and the corresponding predicted amino acid sequence of the cdn-2 protein.

Figure 6 (SEQ ID NO:10 through SEQ ID NO:19) shows a comparison of N-terminal amino acid sequences of cdn-1, cdn-2 and known bcl-2 family members.

Figure 7 (SEQ ID NO:20 and SEQ ID NO:21) shows the nucleotide sequences and translated amino acid sequences of cdn-3.

Figure 8 shows the anti-apoptotic effects of cdn-1 and some of its derivatives in serum-deprivation induced apoptosis of WIL-2 cells.

Figure 9 shows anti-apoptotic effects of cdn-1 and some of its derivatives in FAS-induced apoptosis of WIL-2 cells.

Figure 10 shows modulation of apoptosis by cdn-1 and cdn-2 in FL5.12 cells.

Figure 11 (SEQ ID NO:22) depicts the cdn-1 derivative proteins Δ1, Δ2 and Δ3. The N-terminal residues are indicated by the arrows. The remainder of the derivative proteins is the same as full-length cdn-1.

Detailed Description of the Invention

The present invention encompasses substantially purified nucleotide sequences encoding the novel bcl-2 homologs, cdn-1 and cdn-2; and the proteins encoded thereby; compositions comprising cdn-1 and cdn-2 genes and proteins and methods of use of thereof. Note that in copending United States patent application Serial No. 08/160,067, cdn-1 was termed cdi-1; although the name has been changed, the nucleotide sequence remains identical. The invention further includes recombinant cells and transgenic animals expressing the cloned cdn-1 or cdn-2

cdn-1 is on human chromosome 6 and that cdn-2 is on human chromosome 20. There is also a member of the family cdn-3 which is on human chromosome 11. Fluorescence in situ hybridization (FISH) indicated an approximate location of cdn-1 to be at 6p21-23. Within this region resides the gene for spinocerebellar ataxia type 1. Interestingly, apoptosis has been proposed recently to be involved in the related genetic disorder ataxia telangiectasia. Taken together with the chromosomal localization and the expression of cdn-1 in brain tissue, this suggests the possibility that cdn-1/cdn-2 might represent the SCA1 gene locus. It is possible that cdn-2 and cdn-3 are pseudogenes. While these may not be expressed endogenously, they are capable of expression from a recombinant vector providing the appropriate promoter sequences. Thus, both cdn-2 and cdn-3 genes are encompassed by the present invention as are recombinant constructs thereof and proteins encoded thereby.

Derivatives of the genes and proteins include any portion of the protein, or gene encoding the protein, which retains apoptosis modulating activity. Figure 10 depicts three such derivatives of cdn-1 which have been shown to retain apoptosis-modulating activity. These derivatives, cdn1-Δ1, cdn1-Δ2 and cdn1-Δ3, are encompassed by the present invention.

The invention includes modifications to cdn DNA sequences such as deletions, substitutions and additions particularly in the non-coding regions of genomic DNA. Such changes are useful to facilitate cloning and modify gene expression.

Various substitutions can be made within the coding region that either do not alter the amino acid residues encoded or result in conservatively substituted amino acid residues. Nucleotide substitutions that do not alter the amino acid residues encoded are useful for

optimizing gene expression in different systems. Suitable substitutions are known to those of skill in the art and are made, for instance, to reflect preferred codon usage in the particular expression systems.

The invention encompasses functionally equivalent variants and derivatives of cdns which may enhance, decrease or not significantly affect the properties of CDNs. For instance, changes in the DNA sequence that do not change the encoded amino acid sequence, as well as those that result in conservative substitutions of amino acid residues, one or a few amino acid deletions or additions, and substitution of amino acid residues by amino acid analogs are those which will not significantly affect its properties.

Amino acid residues which can be conservatively substituted for one another include but are not limited to: glycine/alanine; valine/isoleucine/leucine; asparagine/glutamine; aspartic acid/glutamic acid; serine/threonine; lysine/arginine; and phenylalanine/tyrosine. Any conservative amino acid substitution which does not significantly affect the properties of CDNs is encompassed by the present invention.

Techniques for nucleic acid manipulation useful for the practice of the present invention are described in a variety of references, including but not limited to, Molecular Cloning: A Laboratory Manual, 2nd ed., Vol. 1-3, eds. Sambrook et al. Cold Spring Harbor Laboratory Press (1989); and Current Protocols in Molecular Biology, eds. Ausubel et al., Greene Publishing and Wiley-Interscience: New York (1987) and periodic updates.

The invention further embodies a variety of DNA vectors having cloned therein the cdn nucleotide sequences encoding CDNs. Suitable vectors include any known

in the art including, but not limited to, those for use in bacterial, mammalian, yeast and insect expression systems. Specific vectors are known in the art and need not be described in detail herein.

The vectors may also provide inducible promoters for expression of the cdns. Inducible promoters are those which do not allow constitutive expression of the gene but rather, permit expression only under certain circumstances. Such promoters may be induced by a variety of stimuli including, but not limited to, exposure of a cell containing the vector to a ligand, metal ion, other chemical or change in temperature.

These promoters may also be cell-specific, that is, inducible only in a particular cell type and often only during a specific period of time. The promoter may further be cell cycle specific, that is, induced or inducible only during a particular stage in the cell cycle. The promoter may be both cell type specific and cell cycle specific. Any inducible promoter known in the art is suitable for use in the present invention.

The invention further includes a variety of expression systems transfected with the vectors. Suitable expression systems include but are not limited to bacterial, mammalian, yeast and insect. Specific expression systems and the use thereof are known in the art and are not described in detail herein.

The invention encompasses *ex vivo* transfection with cdns, in which cells removed from animals including man are transfected with vectors encoding CDNs and reintroduced into animals. Suitable transfected cells include individual cells or cells contained within whole tissues. In addition, *ex vivo* transfection can include the transfection of cells derived from an animal other than the animal or human subject into which the cells are

ultimately introduced. Such grafts include, but are not limited to, allografts, xenografts, and fetal tissue transplantation.

Essentially any cell or tissue type can be treated in this manner. Suitable cells include, but are not limited to, cardiomyocytes and lymphocytes. For instance, lymphocytes, removed, transfected with the recombinant DNA and reintroduced into an HIV-positive patient may increase the half-life of the reintroduced T cells.

As an example, in treatment of HIV-infected patients by the above-described method, the white blood cells are removed from the patient and sorted to yield the $CD4^+$ cells. The $CD4^+$ cells are then transfected with a vector encoding CDNs and reintroduced into the patient. Alternatively, the unsorted lymphocytes can be transfected with a recombinant vector having at least one cdn under the control of a cell-specific promoter such that only $CD4^+$ cells express the cdn genes. In this case, an ideal promoter would be the CD4 promoter; however, any suitable $CD4^+$ T cell-specific promoter can be used.

Further, the invention encompasses cells transfected *in vivo* by the vectors. Suitable methods of *in vivo* transfection are known in the art and include, but are not limited to, that described by Zhu et al. (1993) Science 261:209-211. *In vivo* transfection by cdns may be particularly useful as a prophylactic treatment for patients suffering from atherosclerosis. Elevated modulation of the levels of CDN could serve as a prophylaxis for the apoptosis-associated reperfusion damage that results from cerebral and myocardial infarctions. In these patients with a high risk of stroke and heart attack, the apoptosis and reperfusion

damage associated with arterial obstruction could be prevented or at least mitigated.

Infarctions are caused by a sudden insufficiency of arterial or venous blood supply due to emboli, thrombi, or pressure that produces a macroscopic area of necrosis; the heart, brain, spleen, kidney, intestine, lung and testes are likely to be affected. Apoptosis occurs to tissues surrounding the infarct upon reperfusion of blood to the area; thus, modulation of CDN levels, achieved by a biological modifier-induced change in endogenous production or by *in vivo* transfection, could be effective at reducing the severity of damage caused by heart attacks and stroke.

Transgenic animals containing the recombinant DNA vectors are also encompassed by the invention. Methods of making transgenic animals are known in the art and need not be described in detail herein. For a review of methods used to make transgenic animals, see, e.g. PCT publication no. WO 93/04169. Preferably, such animals express recombinant cdns under control of a cell-specific and, even more preferably, a cell cycle specific promoter.

In another embodiment, diagnostic methods are provided to detect the expression of cdns either at the protein level or the mRNA level. Any antibody that specifically recognizes CDNs is suitable for use in CDN diagnostics. Abnormal levels of CDNs are likely to be found in the tissues of patients with diseases associated with inappropriate apoptosis; diagnostic methods are therefore useful for detecting and monitoring biological conditions associated with such apoptosis defects. Detection methods are also useful for monitoring the success of CDN-related therapies.

Purification or isolation of CDNs expressed either by the recombinant DNA or from biological sources

such as tissues can be accomplished by any method known in the art. Protein purification methods are known in the art. Generally, substantially purified proteins are those which are free of other, contaminating cellular substances, particularly proteins. Preferably, the purified CDNs are more than eighty percent pure and most preferably more than ninety-five percent pure. For clinical use as described below, the CDNs are preferably highly purified, at least about ninety-nine percent pure, and free of pyrogens and other contaminants.

Suitable methods of protein purification are known in the art and include, but are not limited to, affinity chromatography, immunoaffinity chromatography, size exclusion chromatography, HPLC and FPLC. Any purification scheme that does not result in substantial degradation of the protein is suitable for use in the present invention.

The invention also includes the substantially purified CDNs having the amino acid residue sequences depicted in Figures 3 and 5, respectively. The invention encompasses functionally equivalent variants of CDNs which do not significantly affect their properties and variants which retain the same overall amino acid sequence but which have enhanced or decreased activity. For instance, conservative substitutions of amino acid residues, one or a few amino acid deletions or additions, and substitution of amino acid residues by amino acid analogs are within the scope of the invention.

Amino acid residues which can be conservatively substituted for one another include but are not limited to: glycine/alanine; valine/isoleucine/leucine; asparagine/glutamine; aspartic acid/glutamic acid; serine/threonine; lysine/arginine; and phenylalanine/tyrosine. Any conservative amino acid substitution which does not significantly affect the

properties of CDNs is encompassed by the present invention.

Suitable antibodies are generated by using the CDNs as an antigen or, preferably, peptides encompassing the CDN regions that lack substantial homology to the other gene products of the bcl family. Methods of detecting proteins using antibodies and of generating antibodies using proteins or synthetic peptides are known in the art and are not be described in detail herein.

CDN protein expression can also be monitored by measuring the level of cdn mRNA. Any method for detecting specific mRNA species is suitable for use in this method. This is easily accomplished using the polymerase chain reaction (PCR). Preferably, the primers chosen for PCR correspond to the regions of the cdn genes which lack substantial homology to other members of the bcl gene family. Alternatively, Northern blots can be utilized to detect cdn mRNA by using probes specific to cdns. Methods of utilizing PCR and Northern blots are known in the art and are not described in detail herein.

Methods of treatment with cdns also include modulating cellular expression of cdns by increasing or decreasing levels of cdn mRNA or protein. Suitable methods of increasing cellular expression of cdn include, but are not limited to, increasing endogenous expression and transfecting the cells with vectors encoding cdns. Cellular transfection is discussed above and is known in the art. Suitable indications for increasing endogenous levels of cdn include, but are not limited to, malignancies and cardiac-specific over-expression. Cardiac specific over-expression is particularly suitable for use in indications including, but not limited to, patients susceptible to heart disease and in advance of cardiotoxic therapies including, but not limited to,

chemotherapies such as adriamycin, so as to offer cardioprotection.

In addition, increasing endogenous expression of cdns can be accomplished by exposing the cells to biological modifiers that directly or indirectly increase levels of CDNs either by increasing expression or by decreasing degradation of cdn mRNA. Suitable biological modifiers include, but are not limited to, molecules and other cells. Suitable molecules include, but are not limited to, drugs, cytokines, small molecules, hormones, combinations of interleukins, lectins and other stimulating agents e.g. PMA, LPS, bispecific antibodies and other agents which modify cellular functions or protein expression. Cells are exposed to such biological modifiers at physiologically effective concentrations, and the expression of cdns is measured relative to a control not exposed to the biological modifiers. Those biological modifiers which increase expression of cdns relative to the control are selected for further study.

The invention further encompasses a method of decreasing endogenous levels of cdns. The methods of decreasing endogenous levels of cdns include, but are not limited to, antisense nucleotide therapy and down-regulation of expression by biological modifiers. Antisense therapy is known in the art and its application will be apparent to one of skill in the art.

Screening for therapeutically effective biological modifiers is done by exposing the cells to biological modifiers which may directly or indirectly decrease levels of CDNs either by decreasing expression or by increasing the half-life of cdn mRNA or CDNs. Suitable biological modifiers include, but are not limited to, molecules and other cells. Suitable molecules include, but are not limited to, drugs, cytokines, small molecules, hormones, combinations of

interleukins, lectins and other stimulating agents e.g. PMA, LPS, bispecific antibodies and other agents which modify cellular functions or protein expression. Cells are grown under conditions known to elicit expression of at least one cdn (preferably cdn-1), exposed to such biological modifiers at physiologically effective concentrations, and the expression of cdns is measured relative to a control not exposed to biological modifiers. Those biological modifiers which decrease the expression of cdns relative to a control are selected for further study. Cell viability is also monitored to ensure that decreased cdn expression is not due to cell death.

In determining the ability of biological modifiers to modulate (increase or decrease) cdn expression, the levels of endogenous expression may be measured or the levels of recombinant fusion proteins under control of cdn-specific promoter sequences may be measured. The fusion proteins are encoded by reporter genes.

Reporter genes are known in the art and include, but are not limited to chloramphenicol acetyl transferase (CAT) and β-galactosidase. Expression of cdn-1 and -2 can be monitored as described above either by protein or mRNA levels. Expression of the reporter genes can be monitored by enzymatic assays, or antibody-based assays, like ELISAs and RIAs, also known in the art. Potential pharmaceutical agents can be any therapeutic agent or chemical known to the art, or any uncharacterized compounds derived from natural sources such as fungal broths and plant extracts. Preferably, suitable pharmaceutical agents are those lacking substantial cytotoxicity and carcinogenicity.

Suitable indications for modulating endogenous levels of cdns are any in which cdn-mediated apoptosis is

involved. These include, but are not limited to, various types of malignancies and other disorders resulting in uncontrolled cell growth such as eczema, or deficiencies in normal programmed cell death such as malignancies, including, but not limited to, B cell lymphomas.

The invention also encompasses therapeutic methods and compositions involving treatment of patients with biological modifiers to increase or ~~decreast~~ decrease expression of cdns. Effective concentrations and dosage regimens may be empirically derived. Such derivations are within the skill of those in the art and depend on, for instance, age, weight and gender of the patient and severity of the disease. Alternatively, patients may be directly treated with either native or recombinant CDNs. The CDNs should be substantially pure and free of pyrogens. It is preferred that the recombinant CDNs be produced in a mammalian cell line so as to ensure proper glycosylation. CDNs may also be produced in an insect cell line and will be glycosylated.

For therapeutic compositions, a therapeutically effective amount of substantially pure CDN is suspended in a physiologically accepted buffer including, but not limited to, saline and phosphate buffered saline (PBS) and administered to the patient. Preferably administration is intravenous. Other methods of administration include but are not limited to, subcutaneous, intraperitoneal, gastrointestinal and directly to a specific organ, such as intracardiac, for instance, to treat cell death related to myocardial infarction.

Suitable buffers and methods of administration are known in the art. The effective concentration of a CDN will need to be determined empirically and will depend on the type and severity of the disease, disease

progression and health of the patient. Such determinations are within the skill of one in the art.

Bcl-2 is thought to function in an antioxidant pathway. Veis et al. (1993) Cell 75:229-240. Therefore, therapy involving CDNs is suitable for use in conditions in which superoxide is involved. Administration of CDNs results in an increased extracellular concentration of CDNs, which is thought to provide a method of directly inhibiting superoxide accumulation that may be produced by the blebs associated with apoptosis. The therapeutic method thus includes, but is not limited to, inhibiting superoxide mediated cell injury.

Suitable indications for therapeutic use of CDNs are those involving free radical mediated cell death and include, but are not limited to, conditions previously thought to be treatable by superoxide dismutase. Such indications include but are not limited to HIV infection, autoimmune diseases, cardiomyopathies, neuronal disorders, hepatitis and other liver diseases, osteoporosis, and shock syndromes, including, but not limited to, septicemia.

Hybridization of cloned cdn DNA to messenger mRNA from various regions of the brain indicated high levels of expression of cdn-1 in each of the regions studied (Figure 8). Therefore, neurological disorders are another area in which therapeutic applications of CDNs may be indicated.

The following examples are provided to illustrate but not limit the present invention. Unless otherwise specified, all cloning techniques were essentially as described by Sambrook et al. (1989) and all reagents were used according to the manufacturer's instructions.

Example 1

Identification and Cloning of cdn-1 cDNA

An amino acid sequence comparison of the six known bcl-2 family members (Figure 6) revealed two regions with considerable sequence identity, namely amino acids 144-150 and 191-199. In an attempt to identify new bcl-2 family members, degenerate PCR primers based on sequences in these regions were designed (Figure 1) and PCR was performed using human heart cDNA and human B lymphoblastoid cell line (WIL-2) cDNA. PCR was performed using the Hot Start/Ampliwax technique (Perkin Elmer Cetus). The final concentration of the PCR primers and the template cDNA were 4 μM and 0.1-0.2 ng/ml, respectively. The conditions for cDNA synthesis were identical to those for first strand cDNA synthesis of the cDNA library as described below. PCR was performed in a Perkin Elmer Cetus DNA Thermal Cycler according to the method described by Kiefer et al. (1991) Biochem. Biophys. Res. Commun. 176:219-225, except that the annealing and extension temperatures during the first 10 cycles were 36°C. Following PCR, samples were treated with 5 units of DNA polymerase I, Klenow fragment for 30 min at 37°C and then fractionated by electrophoresis on a 7% polyacrylamide, 1 X TBE (Tris/borate/EDTA) gel. DNA migrating between 170-210 base pars was excised from the gel, passively eluted for 16 hours with gentle shaking in 10 mM Tris-HCl pH 7.5, 1 mM EDTA (TE), purified by passage over an Elutip-D column (Schleicher and Schuell), ligated to the pCR-Script vector (Stratagene) and transformed into *Escherichia coli* strain XL1-Blue MRF (Stratagene). Plasmid DNA from transformants (white colonies) containing both the heart and WIL-2 PCR products was isolated using the Magic Miniprep DNA Purification System (Promega), and the DNA inserts were sequenced by the dideoxy chain termination method

according to Sanger et al. (1977) Proc. Natl. Acad. Sci. USA 74:5463-5467 (USB, Sequenase version 2.0). DNA sequence analysis of the eleven heart PCR products revealed two sequences identical to bcl-x (Boise et al. (1993) Cell 74:597-608) and ten other sequences unrelated to the bcl-2 family.

DNA sequence analyses of the eleven WIL-2 PCR products yielded one bcl-x sequence, five sequences identical to another bcl-2 family member, bax (Oldvai et al. (1993) Cell 74:609-619), four unrelated sequences and one novel bcl-2 related sequence, termed cdn-1. The unique cdn-1 amino acid sequence encoded by the PCR product is shown in Figure 6 from amino acid 151-190 (top row).

To isolate the cdn-1 cDNA, a human heart cDNA library (Clontech) and a WIL-2 cDNA library, constructed as described by Zapf et al. (1990) J. Biol. Chem. 265:14892-14898 were screened using the cdn-1 PCR DNA insert as a probe. The DNA was ^{32}P-labeled according to the method described by Feinberg and Vogelstein (1984) Anal. Biochem. 137:266-267 and used to screen 150,000 recombinant clones from both libraries according to the method described by Kiefer et al. (1991). Eight positive clones from the WIL-2 cDNA library and two positive clones from the heart cDNA library were identified. Four clones from the WIL-2 cDNA library and two from the heart cDNA library were further purified and plasmid DNA containing the cDNA inserts was excised from the λZAPII vector (Stratagene) (Figure 2). The two longest clones, W7 (2.1 kb) and W5 (2.0 kb) were sequenced and shown to contain the cdn-1 probe sequence, thus confirming their authenticity. The heart cDNAs also encoded cdn-1.

The W7 DNA sequence along with the deduced amino acid residue sequence is shown in Figure 2. The deduced amino acid sequence of cdn-1 was also aligned for

maximum sequence identity with the other bcl-2 family members and is shown in Figure 6. As can be seen, there is considerable sequence identity between cdn-1 and other family members between amino acids 100 and 200. Beyond this central region, sequence conservation falls off sharply. Like bcl-2, cdn-1 appears to be an intracellular protein in that it does not contain a either a hydrophobic signal peptide or N-linked glycosylation sites. Cdn-1 does contain a hydrophobic C-terminus that is also observed with all bcl-2 family members except LMW5-HL, suggesting its site of anti-apoptotic activity, like that of bcl-2, is localized to a membrane bound organelle such as the mitochondrial membrane, the endoplasmic reticulum or the nuclear membrane. Hockenbery et al. (1990); Chen-Levy et al. (1989) Mol. Cell. Biol. 9:701-710; Jacobsen et al. (1993) Nature 361:365-369; and Monighan et al. (1992) J. Histochem. Cytochem. 40:1819-1825.

Example 2

Northern Blot Analysis of cDNA Clones

Northern blot analysis was performed according to the method described by Lehrach et al. (1977) Biochem. 16:4743-4651 and Thomas (1980) Proc. Natl. Acad. Sci. USA 77:5201-5205. In addition, a human multiple tissue Northern blot was purchased from Clontech. The coding regions of bcl-2 and cdn-1 cDNAs were labeled by the random priming method described by Feinberg and Vogelstein (1984) Anal. Biochem. 137:266-267. Hybridization and washing conditions were performed according to the methods described by Kiefer et al. (1991).

The results, presented in Figure 4 indicate that cdn-1 is expressed in all organs tested (heart, brain, placenta, lung, liver, skeletal muscle, kidney and

pancreas) whereas bcl-2 is not expressed or expressed at only low levels in heart, brain, lung, and liver. Thus, cdn-1 appears to be more widely expressed throughout human organs than bcl-2 and may be more important in regulating apoptosis in these tissues.

Example 3

Expression of Recombinant cdn-1

In order to express recombinant cdn-1 in the baculovirus system, the cdn-1 cDNA generated in Example 1 was used to generate a novel cdn-1 vector, by a PCR methodology as described in Example 1, using primers from the 3′ and 5′ flanking regions of the gene which contain restriction sites to facilitate cloning. The plasmids were sequenced by the dideoxy terminator method (Sanger *et al.*, 1977) using sequencing kits (USB, Sequenase version 2.0) and internal primers. This was to confirm that no mutations resulted from PCR.

A clone was used to generate recombinant viruses by *in vivo* homologous recombination between the overlapping sequences of the plasmid and AcNPV wild type baculovirus. After 48 hours post-transfection in insect *Spodoptera frugiperda* clone 9 (SF9) cells, the recombinant viruses were collected, identified by PCR and further purified. Standard procedures for selection, screening and propagation of recombinant baculovirus were performed (Invitrogen). The molecular mass, on sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE), of the protein produced in the baculovirus system was compared with the predicted molecular mass of cdn-1 according to the amino-acid sequence.

In addition, similar clones can be expressed preferably in a yeast intracellular expression system by any method known in the art, including the method

described by Barr et al. (1992) Transgenesis ed. JAH Murray, (Wiley and Sons) pp. 55-79.

Example 4

Expression of cdn-1 in Mammalian Systems

The cdn-1 coding sequence was excised from a plasmid generated in Example 1, and introduced into plasmids pCEP7, pREP7 and pcDNA3 (Invitrogen) at compatible restriction enzyme sites. pCEP7 was generated by removing the RSV 3'-LTR of pREP7 with XbaI/Asp718, and substituting the CMV promoter from pCEP4 (Invitrogen). 25 μg of each cdn-1-containing plasmid was electroporated into the B lymphoblastoid cell line WIL-2, and stable hygromycin resistant transformants or G418 resistant transformants (pcDNA3 constructs, Fig. 8) expressing cdn-1 were selected.

The coding region of cdns can also be ligated into expression vectors capable of stably integrating into other cell types including but not limited to cardiomyocytes, neural cell lines such as GTI-7 and TNF sensitive cells such as the human colon adenocarcinoma cell line HT29 so as to provide a variety of assay systems to monitor the regulation of apoptosis by cdn-1.

Example 5

Effect of the Anti-Apoptotic Activity of cdn-1 and its Derivatives in the Wild Type B Lymphoblastoid Cell Line WIL2-729 HF2 and the Transformed Cell Expressing Excess cdn-1

$2x10^5$ WIL-2, and WIL-2 cells transformed with a vector encoding cdn-1 as described in Example 4 are grown in RPMI supplemented with 10% fetal bovine serum (FBS) for the anti-fas experiment or 0.1% FBS for serum deprivation experiments. In the case of the anti-fas experiment, after washing with fresh medium, the cells

were suspended in RPMI supplemented with 10% FBS, exposed to anti-fas antibodies and the kinetics of cell death in response to an apoptosis inducing agent were analyzed by flow cytometry with FACScan. In the case of the serum deprivation experiment, the WIL-2 cells were resuspended in RPMI supplemented with 0.1% FBS and apoptosis was monitored according to the method described by Henderson et al. (1993) Proc. Natl. Acad. Sci. USA 90:8479-8483. Other methods of inducing apoptosis include, but are not limited to, oxygen deprivation in primary cardiac myocytes, NGF withdrawal, glutathione depletion in the neural cell line GTI-7 or TNF addition to the HT29 cell line. Apoptosis was assessed by measuring cell shrinkage and permeability to propidium iodide (PI) during their death. In addition, any other method of assessing apoptotic cell death may be used.

Figure 8 shows the anti-apoptotic response of various WIL-2 transformants to anti-Fas treatment. Figure 9 shows the anti-apoptotic response of various WIL-2 transformants to serum deprivation. In Figure 8, duplicate wells containing $3x10^5$ cells were incubated with 50 ng/ml of the cytocidal anti-Fas antibody for 24 hours. Cell death was then analyzed by flow cytometry with FACScan. The proteins expressed from each construct are shown beneath the columns. Since many of the constructs are truncation or deletion variants, the exact amino acids expressed are also indicated. As can be seen, all of the transformants had some protective effect when compared to the control transformant containing the pREP7 vector alone. The most apoptosis-resistant transformant was the cdn-1Δ2 expressing cell line, in which over 90% of the cells survived anti-fas treatment. Significant protection was also observed in transformants expressing full length cdn-1 (1-211) and cdn-1Δ1, followed by bcl-2Δ and bcl-2 expressing cell lines.

Cdn-1Δ1 and cdn-1Δ2 are lacking the N-terminal 59 and 70 amino acids of the full length cdn-1 molecule, respectively. The observation that cdn-1Δ2 is more effective at blocking apoptosis than full length cdn-1 suggests that smaller, truncated cdn-1 molecules may be potent therapeutics.

Example 6

Determination of other cdn genes and

Cloning of the cdn-2 Gene

Southern blot analyses of human genome DNA and a panel of human/rodent somatic cell DNAs indicated that there were at least 3 cdn related genes and that they resided in chromosomes 6, 11 and 20. PCR/sequence analysis of the three hybrid DNAs showed that cdn-1 was on chromosome 6 and that two closely related sequences were on chromosome 20 (designated cdn-2) and chromosome 11 (designated cdn-3). We have cloned the cdn-2 and cdn-3 genes and sequenced them. Interestingly, both cdn-2 and cdn-3 do not contain introns and have all of the features of processed genes that have returned to the genome. cdn-3 has a nucleotide deletion, causing a frame shift and early termination and thus is probably a pseudogene. Both, however, have promoter elements upstream of the repeats CCAAT, TATAAA boxes but are probably not transcribed. (Northern blot analysis with cdn-2 and cdn-3 specified probes.)

900,000 clones from a human placenta genomic library in the cosmid vector pWE15 (Stratagene, La Jolla, CA) were screened with a 950 bp BglII- HindIII cDNA probe containing the entire coding region of Cdn-1. The probe was ^{32}P-labeled according to the method of Feinberg and Vogelstein (1984) Anal. Biochem. 137:266-267. The library was processed and screened under high stringency hybridization and washing conditions as described by

Sambrook et al. (1989) Molecular Cloning, 2nd edition, Cold Spring Harbor Laboratory Press. Ten double positive clones were further purified by replating and screening as above. Plasmid DNA was purified using the Wizard Maxiprep DNA Purification System as described by the supplier (Promega Corp., Madison, WI) and analyzed by EcoRI restriction enzyme mapping and Southern blotting. The probe used for Southern blotting and hybridization conditions was the same as above.

The cosmid clones fell into two groups as judged by EcoRI restriction analysis and Southern blotting. Cosmid clones (cos) 1-4 and 7 displayed one distinct pattern of EcoRI generated DNA fragments and contained a single 6.5 kb hybridizing EcoRI DNA fragment. Cos2 and Cos9 fell into the second group that was characterized by a 5.5 kb hybridizing EcoRI DNA fragment. The 6.5 kb DNA fragment from cos2 and the 5.5 kb DNA fragment from cos9 were subcloned into pBluescript SK$^-$ (Stratagene, La Jolla, CA) using standard molecular biological techniques (Sambrook et al. as above). Plasmid DNA was isolated and the DNA inserts from two subclones, A4 (from cos2) and C5 (from cos9) were mapped with BamHI, HindIII and EcoRI and analyzed by Southern blotting as described above. Smaller restriction fragments from both clones were subcloned into M13 sequencing vectors and the DNA sequence was determined.

The sequence of A4 contains an open reading frame that displays 97% amino acid sequence identity with cdn-1. (Figure 5) The high degree of sequence identity of this gene with cdn-1 indicates that it is a new cdn-1 related gene and therefore will be called cdn-2. A sequence comparison of the encoded cdn-2 protein and the other members of the bcl-2 family is shown in Figure 5. Cdn-2 contains the conserved regions, BH1 and BH2, that are hallmarks of the bcl-2 family, and displays a lower

overall sequence identity (~20-30%) to other members, which is also characteristic of the bcl-2 family. cdn-3 has a frame shift and therefore does not contain the structural features of cdn-1, cdn-2 or other bcl-2 family members.

Example 7

Chromosomal Localization of the cdn-1 and cdn-2 Genes

Southern blot analysis of a panel of human/rodent somatic cell hybrid DNAs (Panel #2 DNA from the NIGMS, Camden, NJ) and fluorescent in situ hybridization (FISH) of metaphase chromosomes were used to map the cdn genes to human chromosomes. For Southern blotting, 5μg of hybrid panel DNA was digested with EcoRI or BamHI/HindIII, fractionated on 0.8% or 1% agarose gels, transferred to nitrocellulose and hybridized with the cdn-1 probe. Hybridization and washing conditions were as described above. For FISH, the cdn-2 subclone, A4, was biotinylated using the Bionick Labeling System (Gibco BRL, Gaithersburg, MD) and hybridized to metaphase chromosomes from normal human fibroblasts according to the method described by Viegas-Pequignot in In Situ Hybridization, A Practical Approach, 1992, ed. D.G. Wilkinson, pp. 137-158, IRL Press, Oxford. Probe detection using FITC-conjugated avidin and biotinylated goat anti-avidin was according to the method described by Pinkel et al. (1988) Proc. Natl. Acad. Sci. USA 85:9138-9142.

Southern blot analysis showed three hybridizing EcoRI bands in the human DNA control that were approximately 12 kb, 11 kb and 5.5 kb in length. Analysis of the somatic cell hybrid DNA indicated that the 12 kb band was in two different samples, NA10629, which contained only human chromosome 6, and NA07299, which contained both human chromosomes 1 and X and,

importantly, a portion of chromosome 6 telomeric to p21. The 11 kb band was in NA13140, which contains human chromosome 20. The 5.5 kb hybridizing band was found only in sample NA10927A, which contained human chromosome 11. PCR/DNA sequencing analysis of these hybrid DNA samples using primers for cdn-1 or cdn-2, showed cdn-1 sequences in NA10629 (the chromosome 6-containing hybrid DNA) and NA07299 (the chromosome 1, X and 6pter >p21-containing hybrid DNA), indicating that the cdn-1 gene resides on chromosome 6, telomeric to p21. cdn-2 sequences were found in NA13140, indicating the cdn-2 gene resides on chromosome 20, and cdn-3 sequences were found in NA10927A, indicating the cdn-3 gene resides on chromosome 11.

Example 8

Modulation of apoptosis by cdn-1 and cdn-2 in FL5.12 cells

FL5.12 is an IL-3-dependent lymphoid progenitor cell line (McKearn et al. (1985) Proc. Natl. Acad. Sci USA 82:7414-7418) that has been shown to undergo apoptosis following withdrawal of IL-3 but is protected from cell death by overexpression of bcl-2. Nunez et al. (1990) J. Immunol. 144:3602-3610; and Hockenbery et al. (1990) Nature 348:334-336. To assess the ability of cdn-1 and cdn-2 to modulate apoptosis, cDNAs encoding cdn-1, cdn-2, two truncated forms of cdn-1 (described below) and bcl-2 were ligated into the mammalian expression vector, pcDNA3 (Invitrogen, San Diego, CA) and stably introduced into the mouse progenitor B lymphocyte cell line FL5.12 by electroporation and selection in media containing the antibiotic G418. Assays were then performed on bulk transformants as described below.

The effects of the overexpressed genes on FL5.12 cell viability were examined at various times

following withdrawal of IL-3 and are shown in Figure 10. Cell viability was assessed by propidium iodide (PI) exclusion on a flow cytometer (Becton Dickinson FACScan). Bcl-2 expression protected the cells significantly from cell death while cdn-1 appeared to enhance cell death when compared to the vector control. Cdn-2 expression conferred a low level of protection from cell death at earlier times but was insignificant at later time points. Interestingly, cdn-1Δ2 gave a moderate level of protection against cell death. Cdn-1-112, a molecule that contains the N-terminal 112 amino acids of cdn-1, also appeared to partially protect the FL5.12 cells although at lower levels than Bcl-2.

As shown in Example 7, expression of cdn-1 and cdn-1Δ2 in WIL2 cells resulted in increased cell survival in response to anti-Fas-mediated apoptosis and serum withdrawal. Taken together, these data suggest that the various cdn molecules are capable of modulating apoptosis in a positive or negative manner, depending on the cell type and apoptotic stimuli. Thus, they are effective in preventing cell death such as in the post-ischemic reperfusion tissue damage in the heart or in inducing cell death in cells that have escaped apoptotic control, as is the case in various cancers.

Although the foregoing invention has been described in some detail by way of illustration and example for purposes of clarity of understanding, it will be apparent to those skilled in the art that certain changes and modifications may be practiced. Therefore, the description and examples should not be construed as limiting the scope of the invention, which is delineated by the appended claims.